Science Case for
Better Neutron Detectors for Scattering

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Spallation Neutron Source

Experimental Facilities Division

May 29-30, 2003

Spallation Neutron Source at Oak Ridge

SNS – Complete in 2006

Why Neutrons?

Neutron Interactions: coherent scattering
incoherent scattering
magnetic scattering
capture

Thermal Neutrons:

Wavelengths comparable to atomic spacing

Velocities comparable to atomic vibrations

Scattering cross section is nuclear, not electronic

Distinguish isotopes, hydrogen

Sensitive to magnetic moments

Neutrons are a bulk probe – interactions are weak

Detector performance parameters

Neutron capture efficiency at maximum operating energy

50% at 50 meV to 50 eV

Counting efficiency

near 100%

Position resolution

2 cm to 100 μm

Gamma-ray rejection

10^{-6} to 10^{-8}

Rate

10^{2} to 10^{6} n/s/pixel

10^{5} to 10^{8} n/s (whole area)

Time resolution (at a known flight path distance)

1 μs to 10 μs

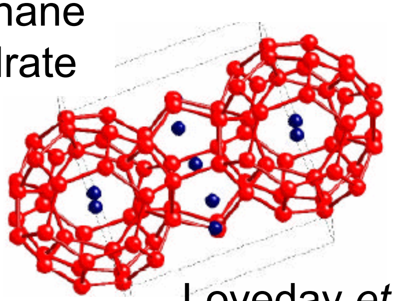
Diffraction

Elastic scattering yields a diffraction pattern dependent on the atomic arrangement of the sample.

Instruments are designed for the type of sample, or for the specialized environment.

Powder
Single Crystal
Liquid/Amorphous/Short-range ordered

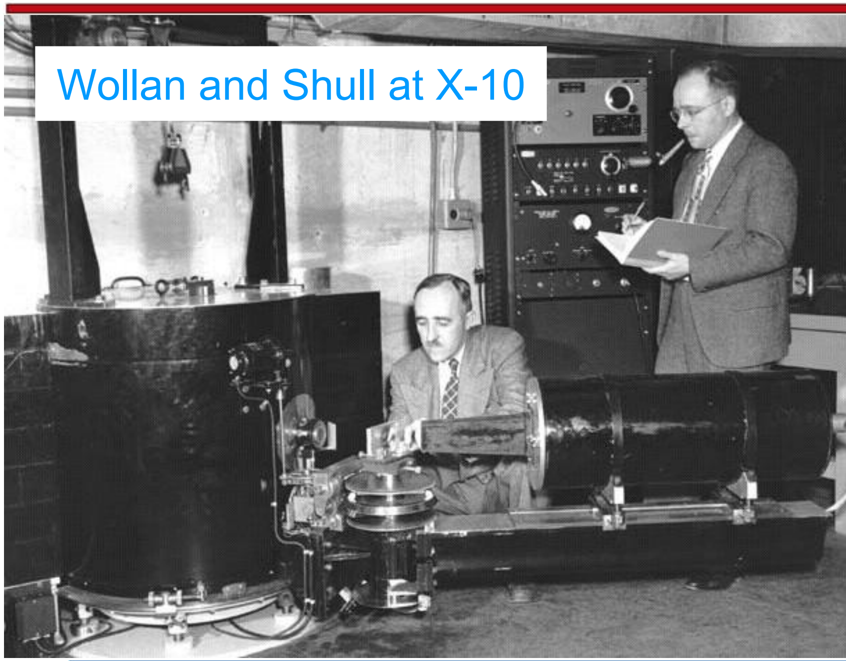
Methane Hydrate

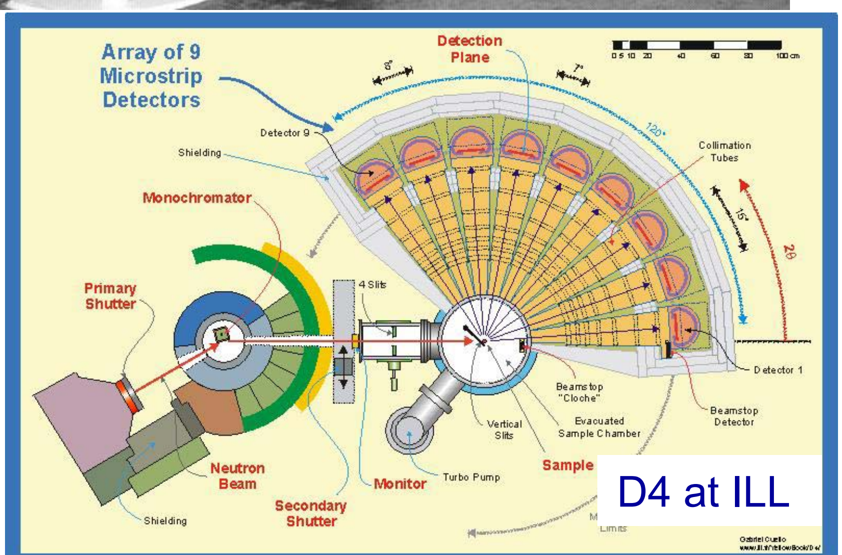


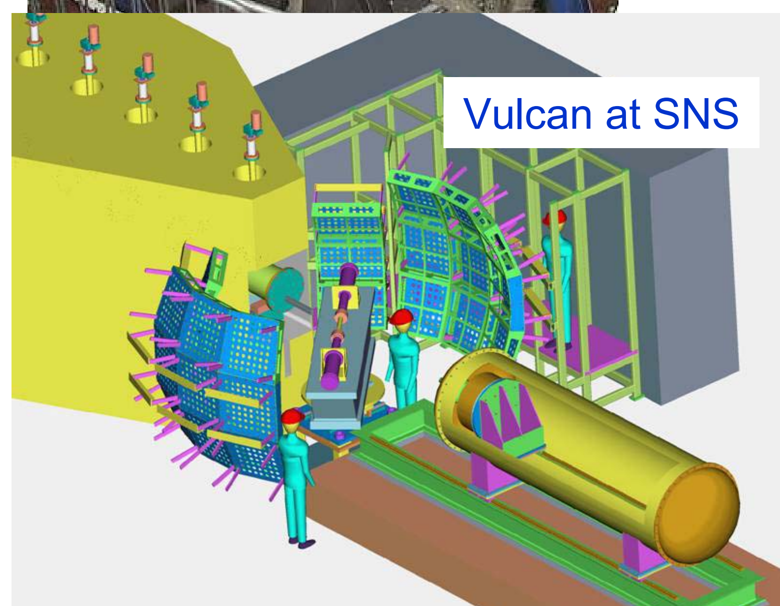
Loveday *et al.*

High pressure
High magnetic field
Engineering materials
- *Residual Stress*
- *Texture*

Some Diffraction Instruments







Powder Diffraction

Nuclear scattering gives atom positions, especially in materials with a combination of heavy and light atoms

Metal oxides – *oxygen positions*
High temperature superconductors
Parametric studies
  Temperature dependence
  Processing dependence

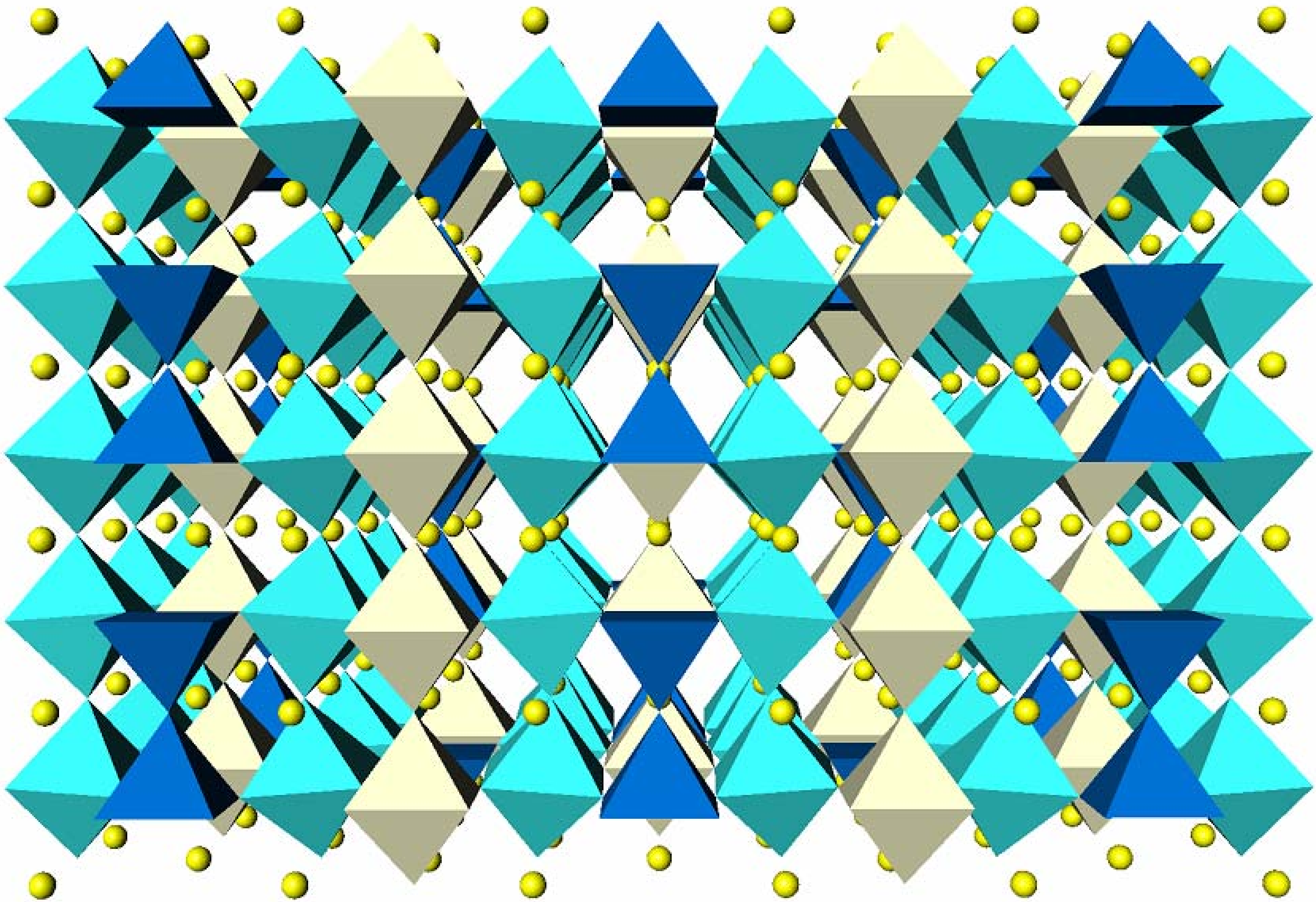
Magnetic scattering -- main source of information about moment ordering in magnets

1st observation of antiferromagnetism, Wollan and Shull

Rietveld Analysis refines atom positions using powder data

Moderate resolution and rate requirements
Very large detector area required – Cost is important!

Oxide Ion Conductor – $Sr_8Fe_8O_{23}$



Correct Crystal Structure

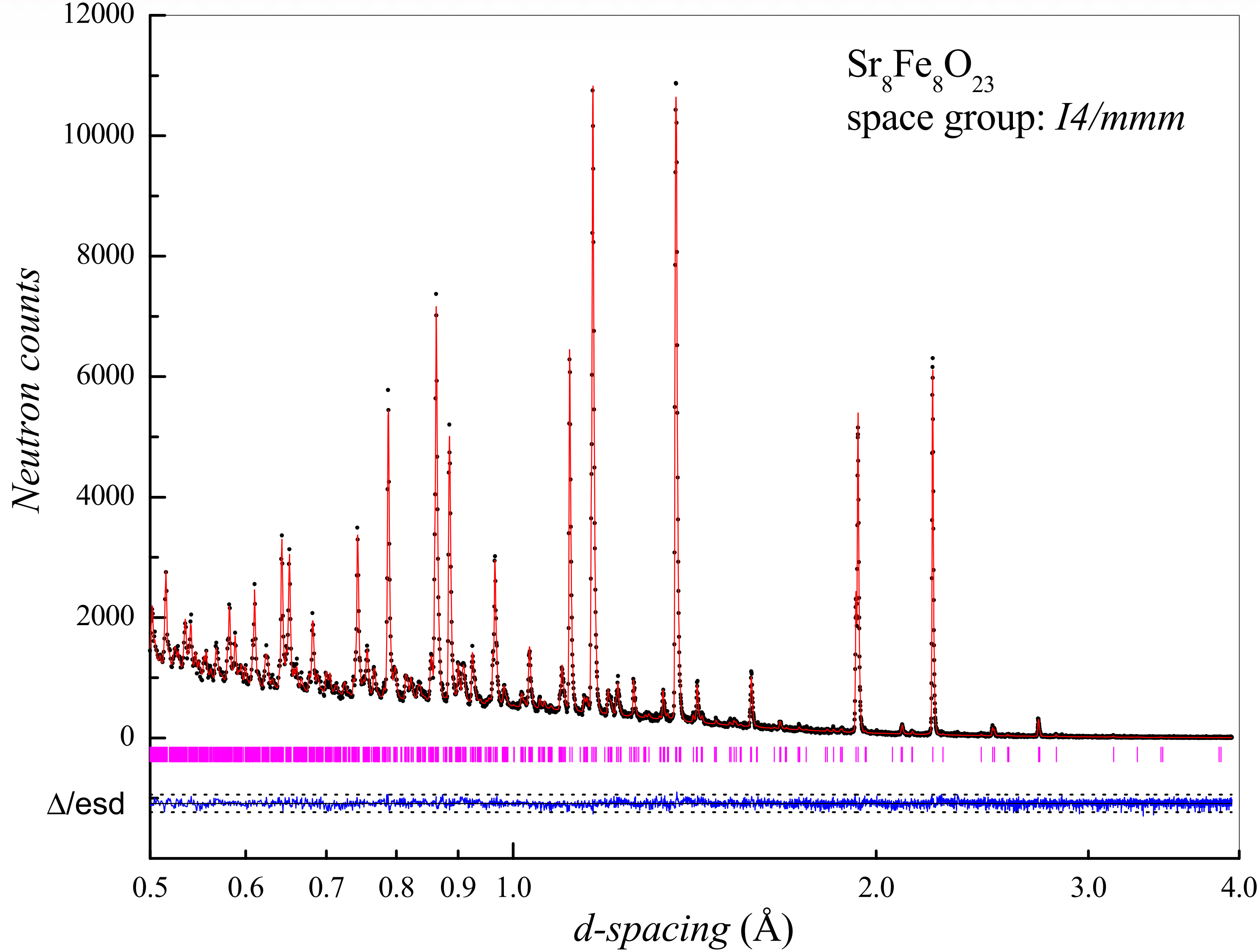


Fig. 5

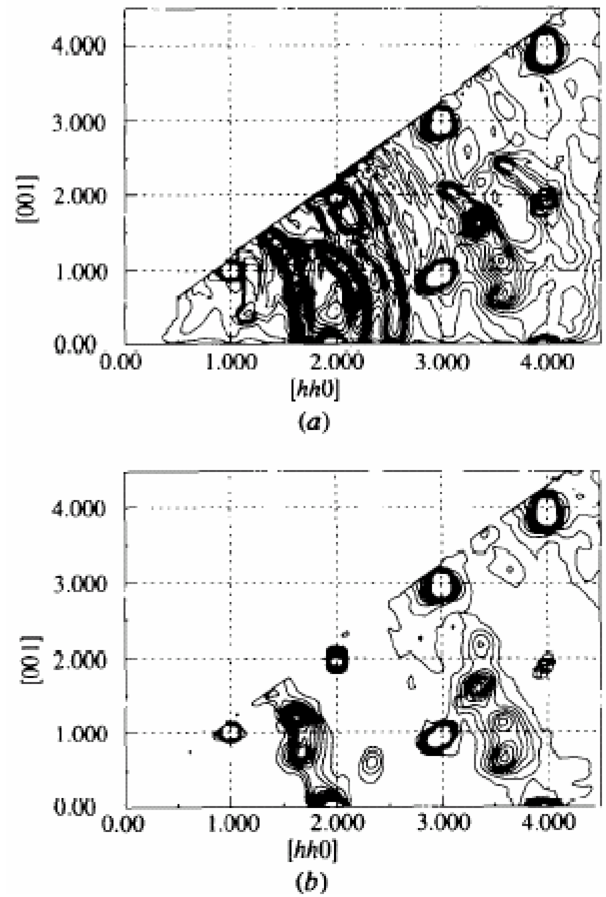
Single Crystal Diffuse Scattering

Bragg peaks give crystal structure

- Light atom positions
  - → especially *Hydrogen*
- Magnetic structure

Diffuse scattering gives information on a larger length scale, such as:

- Magnetic short range order
- Hydrogen distribution in metals
- Contrast between metals in alloys



Proffen et al. (1996). *Acta Cryst.*, **B52**, 66-71.

Example: Cubic Stabilized Zirconia

Bragg peaks are several orders of magnitude larger than the diffuse scattering, but there is little separation in reciprocal space

→ need resolution *and* dynamic range

Detector Needs for Diffraction

"Large-Pixel" (powder, engineering, disordered)

- Very large detector area – low cost required
- High efficiency requirement
  - 20% at 50 eV (disordered)
  - 50% at 1 eV (powder, engineering)

"Small-Pixel" (single crystal)

- High resolution ➔ 1 mm x 1 mm or better
- Large area, low cost needed
- Low γ sensitivity
- Minimal magnetic effects for magnetic or polarized neutron work

Engineering imaging device – 100 micron resolution

Position Sensitive Monitors for Incident Beam

Large Scale Structure Diffraction

Small Angle Neutron Scattering (SANS)

Small Angles ⇔ Low Momentum Transfer ⇔ Large Structures

- Metallurgy, Geology, Polymers ! , Biology
- Nanoscale structures

Requires high resolution 2D detector

Low noise, large dynamic range

Neutron reflectometry ⇔ 1D probe of surfaces and interfaces

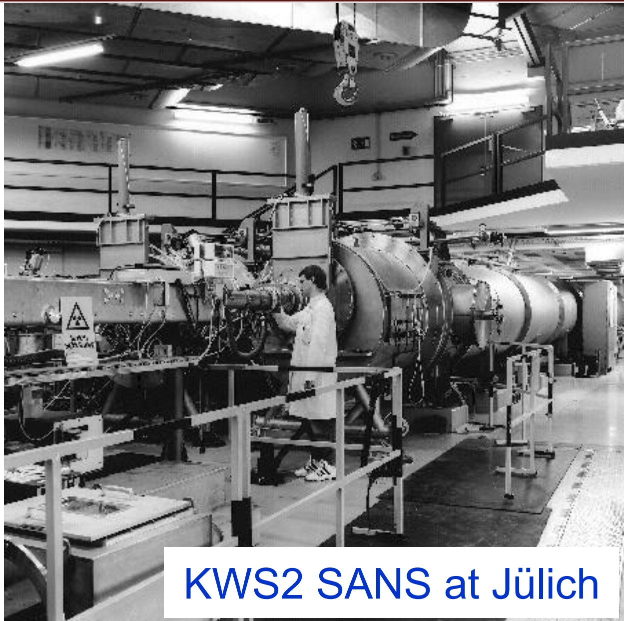
"Sees" scattering length density differences between layers

- Magnetic structure of films
- Manufactured multilayer structures
- Polymers, complex fluids, biological membranes
- Interfaces (inside larger samples)

Detectors similar to SANS

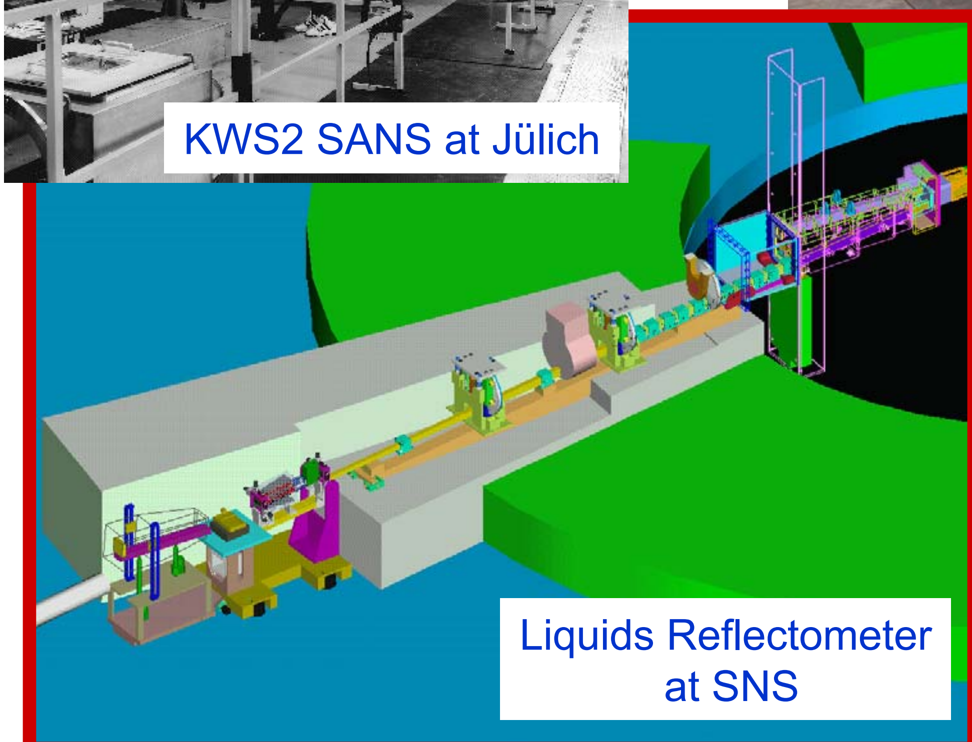
⇔ Total reflection is important ⇔ Very High Rates !

SANS and Reflectometer Instruments

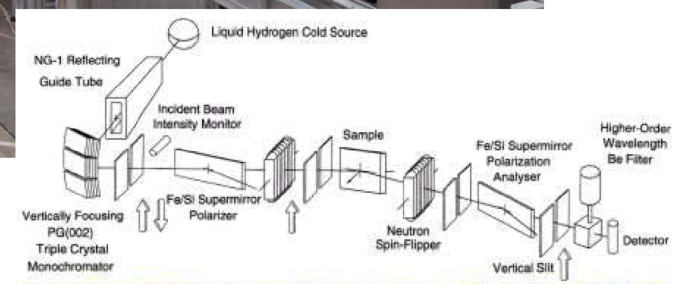


KWS2 SANS at Jülich

Riso SANS at PSI



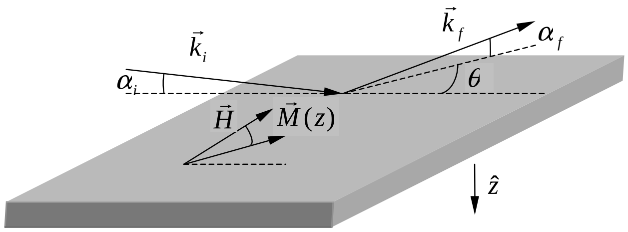
Liquids Reflectometer at SNS



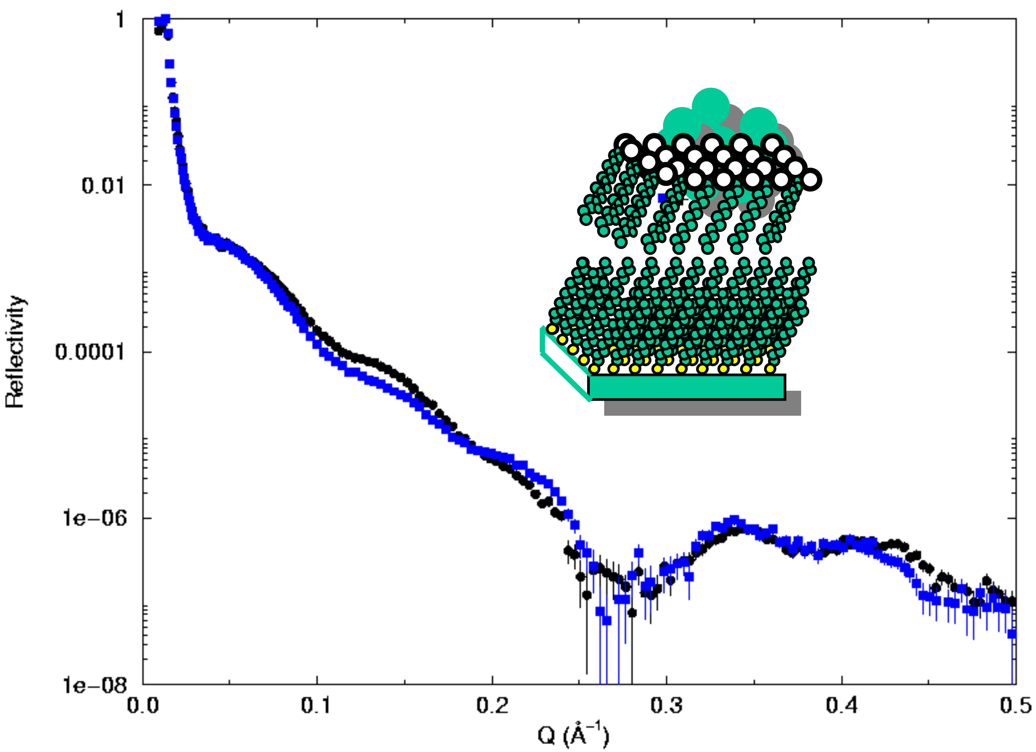
NG1 Reflectometer at NIST

Neutron Reflectometry

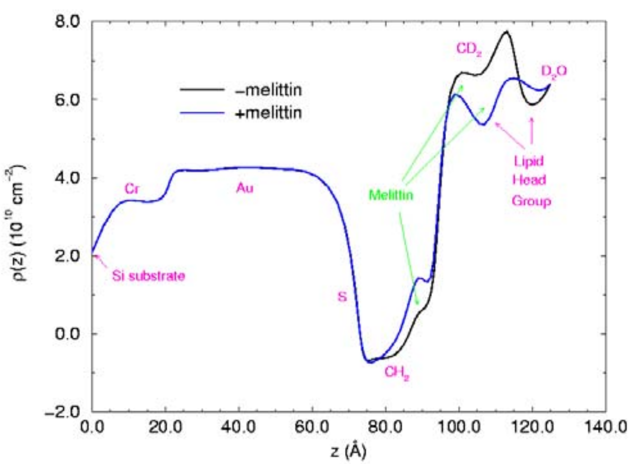
Total reflection > 10^6 n/s/1mm^2 pixel (10^8 n/s)
Dynamic range 1 to 10^{-10}



High Rate, High Resolution,
Low Noise, Low Gamma Sensitivity



Melittin in alkanethiol/phospholipid hybrid bilayer membranes



Krueger *et al.*, Langmuir 17, 511 (2001)
Majkrzak *et al.*, Biophys. J. 79, 3330 (2000)

Detector needs for SANS & Reflectometry

In many cases, detectors require attenuators for low angle positions, not only to prevent saturation but to avoid detector damage.

In many research areas, (melting, self-assembly of membranes, surface/interface formation) there is a desire to observe time-dependent processes on the shortest possible time scale – maybe < 1s!

➔ *Not compatible with mechanical attenuators*

Improved spatial resolution = better instrument resolution

Better angle definition also helps resolution

Big samples, high fluxes – need low ***γ*** sensitivity

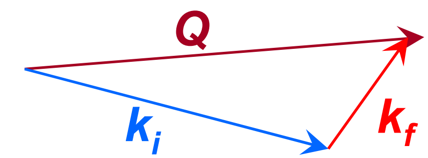
Spatially resolved incident beam monitor

Inelastic Scattering

The change in the velocity of the neutron reveals the momentum and energy of the excitation.

Phonons
Spin Waves
Quasielastic excitations
Molecular vibrations

$\Delta E = E_f - E_i$



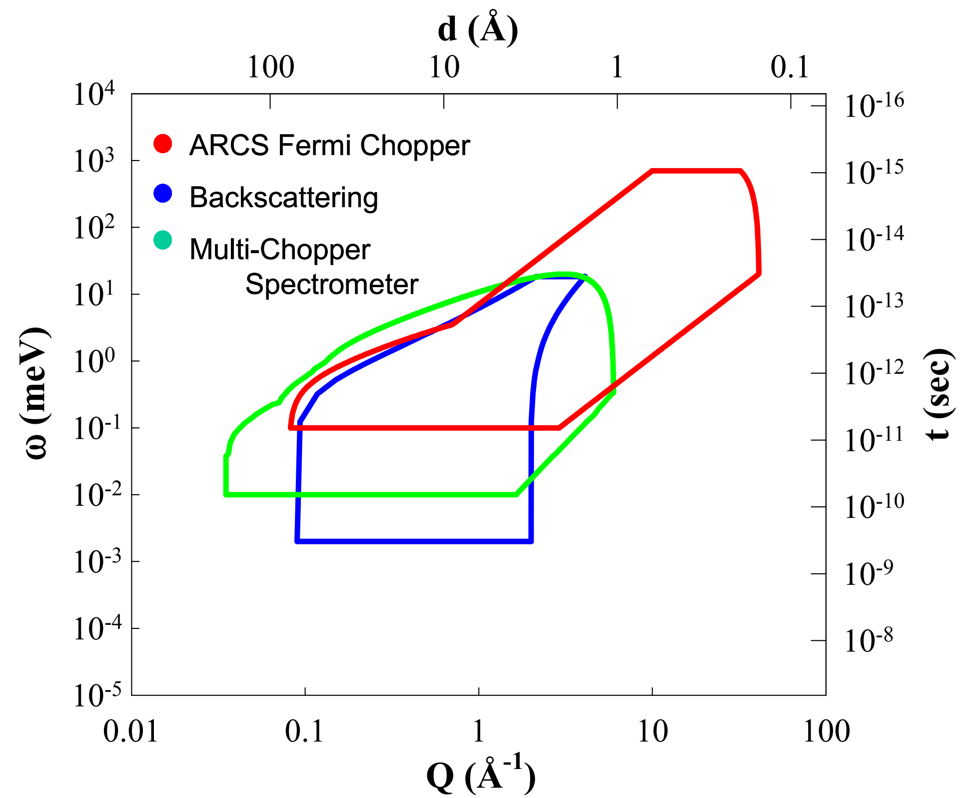
$\sigma_{inelastic} << \sigma_{elastic}$

Small Signals

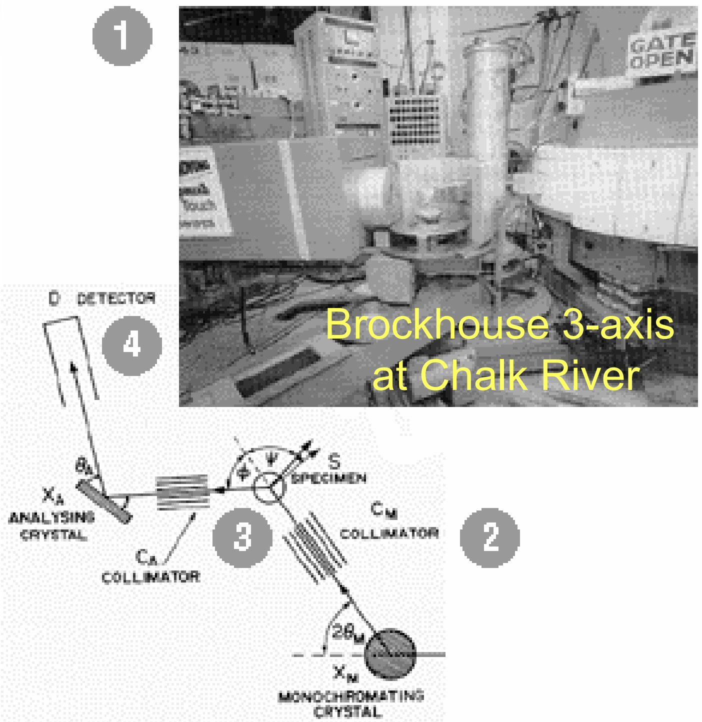
Large Samples

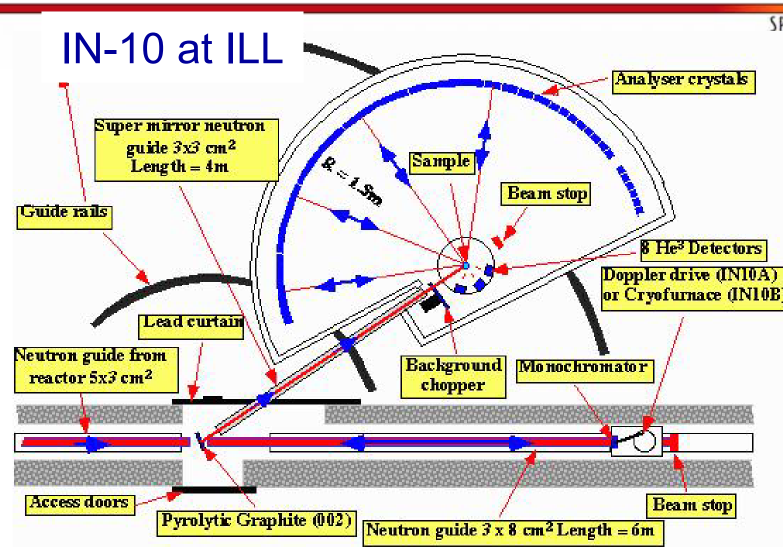
Crystal Analyzer Spectrometers:
Triple Axis, Backscattering
HYSPEC, SNS Backscattering

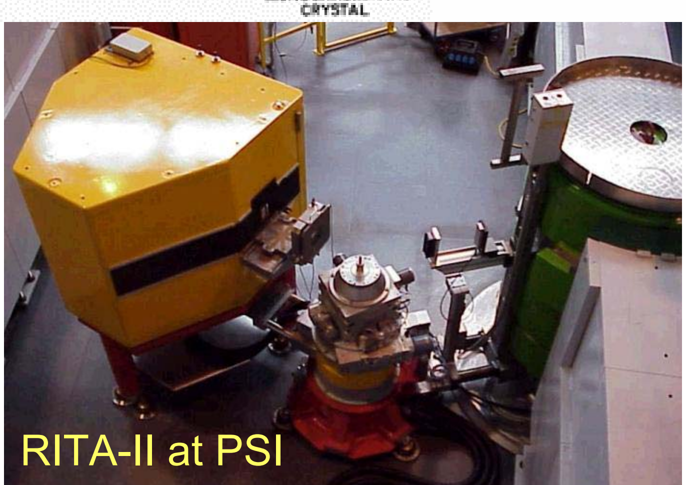
Direct Geometry Spectrometers:
Fermi Chopper, Multi-Chopper
ARCS, CNCS, SEQUOIA

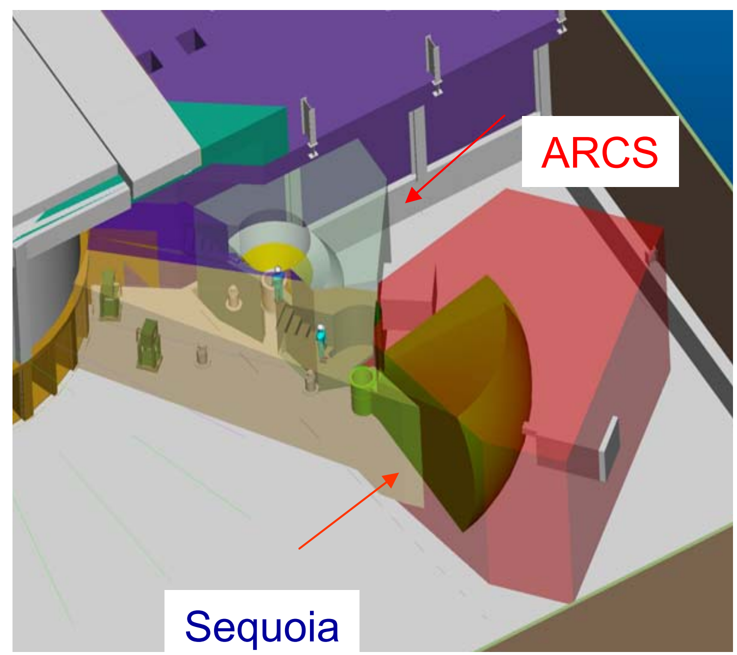


Inelastic Instruments









Fermi Chopper Spectrometer (Direct Geometry)

Fermi Chopper Spectrometers access excitations from ~10 to ~500 meV over a large region in momentum space

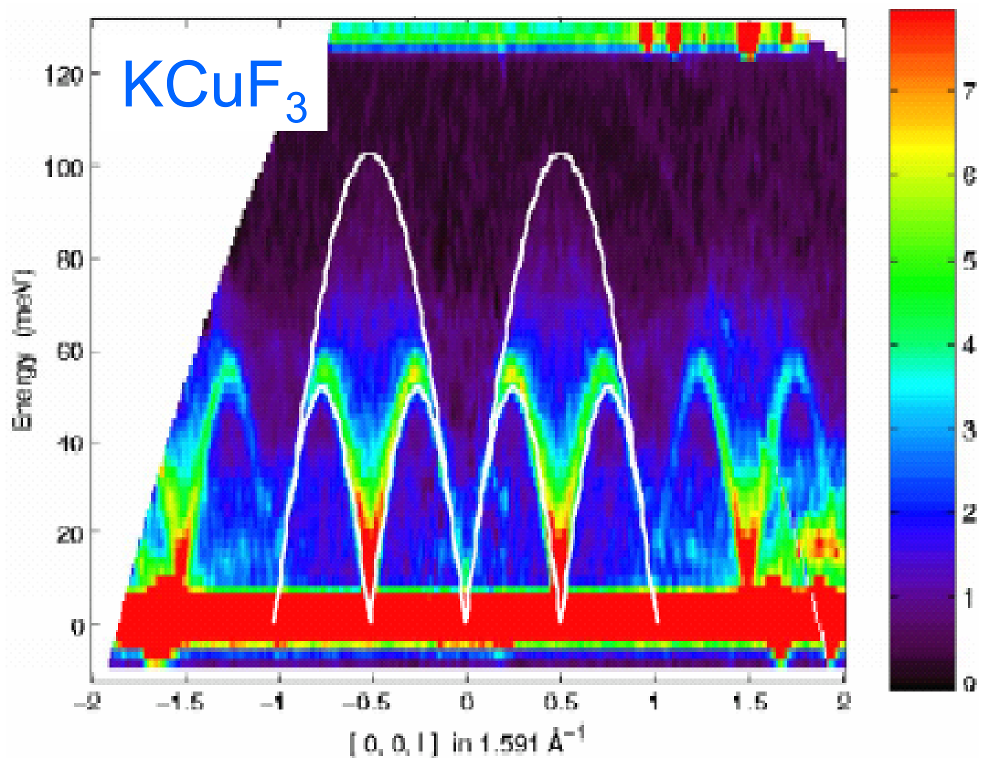
Position Resolution **1 – 2 cm**

Time Resolution **1 μs**

Large Samples,
Powder or Single Crystal

Count rates are modest,
need low noise,
low ***γ*** sensitivity

But Bragg peaks can mean high rates on small spots!



D. A. Tennant *et al*. Phys. Rev. B 52, 13368 (1995)

Detector Needs for Inelastic Scattering

Present ^{3}He LPSD gas detectors do a good job of gamma rejection and have very low noise

Limitations:

Peak Counting Rates -- The inelastic signals have very low counting rates, but elastic single-crystal Bragg peaks can have count rates of > 10^7 n/s (more for triple axis), which can saturate detectors and obscure inelastic features

Time Resolution – Uncertainty in time of arrival and flight path distance affect energy resolution, especially with cold neutrons. In other words, a flat detector is desirable.

Spatial Resolution – Present inelastic instruments are designed for detectors with resolution around 2.5 cm. Better spatial resolution could lead to better momentum resolution, especially with small samples.